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MATERIALS TESTING AND MODELING THAT SUPPORTS YUCCA MOUNTAIN PROJECT WASTE PACKAGE DESIGN AND PERFORMANCE ASSESSMENTS

David Stahl
Framatome Cogema Fuels
Las Vegas, NV

R. Daniel McCright
Lawrence Livermore National Laboratory
Livermore, CA

Considerable progress has been made in the last year in the areas of corrosion testing and modeling areas that support the design of waste packages and performance assessments for the potential repository at Yucca Mountain. The technical areas include: electrochemical potential testing, long-term corrosion testing, galvanic protection, atmospheric corrosion, crack growth rate testing, microbiologically-influenced corrosion, ceramic material mechanical properties, and interactions of the engineered barrier materials.

Electrochemical testing of nickel-base and titanium-base corrosion-resistant alloys continued. For the Fe-Ni-Cr-Mo alloys, Alloy 825, G-3 and G-30 suffered from pitting corrosion in acidic brines at the three levels of chloride tested, with G-30 showing the least attack. Alloy 625 was also tested and it too was attacked but less than the G-30 alloy. Other more corrosion-resistant alloys were tested, including nickel-base Alloy C-4 and Alloy C-22, as well as Ti-Grade 12. These materials exhibited corrosion resistance with no evidence of pitting or general corrosion in any environment tested. These materials maintained their shiny surface appearance even after the exposures to the test solutions.

Long-term corrosion studies are being performed to determine the comprehensive corrosion properties of metallic alloys being considered for constructing the multiple-barrier waste package container. Three classes of materials are to be addressed: corrosion resistant, corrosion allowance, and intermediate. Corrosion properties to be assessed are general corrosion, pitting corrosion, crevice corrosion, intergranular corrosion, stress corrosion cracking, hydrogen embrittlement, and galvanic corrosion. This activity will provide kinetic and mechanistic information about the corrosion degradation of candidate materials. This information will support materials selection, performance analysis, and model development. Tests are conducted in environments that bound the range of environmental conditions and water chemistries that are projected to develop near the container surface over long periods of time. This comprehensive corrosion test is planned for at least five years, with test specimens periodically removed and inspected to measure degradation from corrosion as a function of exposure time.

The first six test vessels, four containing carbon and alloy steel specimens at two temperatures (60^{o} and 90^{o}C) with dilute and concentrated J-13 water chemistries, and two containing Alloy 400 and 70/30 Cu/Ni specimens exposed to the acidified concentrated groundwater environment, at a pH of about 2 and the same two temperatures, continue to operate normally in the long-term corrosion test facility. Results from the first six months of operation will be reported. The second set of six tanks include approximately 4000 specimens of Ni-base and Ti-base corrosion resistant alloys. These tanks are operating with dilute and concentrated J-13 and the acidified concentrated groundwater. Preliminary results will be reported.
Galvanic protection studies will provide an understanding of the electrochemical interaction between the dissimilar metals proposed for multi-barrier designs. The corrosion allowance outer

barrier is expected to provide galvanic protection to the inner barrier, and a first objective is to evaluate the effectiveness of this protection. A second objective is to determine if this protection will function under all circumstances. Galvanic corrosion cells have been designed and built and testing has been initiated.

Thermogravimetric analysis (TGA) studies are being conducted to determine the conditions under which aqueous film corrosion processes occur after emplacement of the waste package, and to characterize the mechanistic processes occurring. The key parameters appear to be humidity, temperature, gaseous contaminants, surface contaminants (salts), and surface condition of the metal. Tests were performed on carbon steel (AISI 1020) specimens with three different surface conditions: clean, polished surfaces; clean, etched surfaces; and salt-covered surfaces. Tests were conducted in the 60 to 90%C temperature range over a wide range of relative humidities at each test temperature. It was found that on clean, polished surfaces high relative humidities (>85%) were necessary to detect enhanced corrosion relative to "dry oxidation" over time periods of about 100 hr. Chemical etching of the surface enhances the susceptibility to electrochemical corrosion at lower relative humidity values. On NaCl covered surfaces, the susceptibility to aqueous film electrochemical corrosion was significantly enhanced relative to the clean surfaces with rates up to 10,000 times faster.

Crack growth testing evaluates the susceptibilities of candidate corrosion-resistant metallic container materials to environment-assisted embrittlement, including stress corrosion cracking and hydrogen embrittlement under metallurgical and environmental conditions relevant to the potential repository. Double cantilever beam test specimens of the corrosion-resistant materials are being tested in controlled temperature baths in acidified chloride solutions at 90%C. Preliminary results with Alloy 825 indicated crack growth and branching after 30 days of exposure. Additional baths and experiments have been set up and the results will be reported.

Microbiologically-influenced corrosion testing has been initiated to determine if corrosion is enhanced by the presence and propagation of microorganisms, particularly bacterial species. Testing has been conducted with carbon steel in microbial corrosion cells under a variety of conditions. Corrosion rates were increased from approximately 25 m/yr (abiotic control) to 38 m/yr, 50 m/yr and 75 m/yr in cell environments containing iron-oxidizers, slime producers, and sulfate reducers alone, respectively; to somewhat higher levels when paired in various combinations. In a mixture of all three bacterial classes, corrosion rates reached a maximum at 125 m/yr and decreased thereafter, probably due to oxygen depletion in the sealed electrochemical measurement cells. Testing has been initiated on the nickel-base materials and preliminary results will be reported.

Mechanical testing of ceramic-coated, carbon steel specimens has been initiated. The ceramic materials include alumina, titania, and alumina-magnesia spinel. The tests include a 3-m drop tower to determine the impact resistance of the coated products. Several tests have already been conducted. Preliminary results will be reported. Also the stability of the gamma phase of alumina has been evaluated.

Testing of engineered materials has been limited to the evaluation of the degradation of concrete and its interaction with waste package materials and the interaction of corroded steel on water chemistry. Effort has also been initiated on the effect of microbes on the degradation of concrete.

Effort has also continued on the generation of models to predict the performance of the materials of the waste package. The recent work has emphasized the model for predicting the pitting

corrosion of the corrosion-resistant materials. Recent improvements to this model have focused on pit growth and the time evolution of the pit depth distribution. This model has been shown to be consistent with extreme-value statistical methods for predicting the logarithmic increase of maximum pit depth with increasing exposed surface area. The model has been augmented with data collected on the distribution of pits in corrosion-resistant materials, particularly Alloy 825.

Work was begun on a deterministic model to predict long-term effects of low-temperature oxidation. The material of focus was carbon steel, the principal candidate for the outer barrier construction material. Eventually, this work will be joined with a companion model on general aqueous corrosion, the transition line being driven by the experimental work on determination of the critical relative humidity for the onset of aqueous effects on the metal surface. The tentative conclusion of the model stated that, based on physically based model calculations, dry oxidation is not expected to significantly degrade the performance of thick, corrosion allowance materials for hundreds to thousands of years.

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